

Title: **FULL SCALE EXPERIMENT ON FOAM BITUMEN  
PAVEMENTS IN CAPTIF ACCELERATED TESTING  
FACILITY**

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## **ABSTRACT**

Foam bitumen stabilization is a viable alternative to reduce aggregate consumption in New Zealand. An accelerated full-scale experiment on foam bitumen pavements was conducted in the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF), as part of a Transit New Zealand research project to study the effects of foam bitumen on unbound granular materials. Six pavement sections were tested. Three were constructed using foam bitumen contents of 1.2%, 1.4% and 2.8% respectively, plus a common active filler content of 1.0% cement. Two more pavements were constructed adding cement only (1.0%), and foam bitumen only (2.2%). In addition, one control section with the untreated unbound material was tested. Strains were collected using a 3D Emu soil strain system installed in each pavement section. Results showed that surface deflections decreased at sections with higher bitumen contents. After the application of 5,710,000 Equivalent Standard Axles (ESAs), the sections stabilized with cement only, bitumen only, and the control section all showed large amounts of rutting. Conversely, little rutting was observed in the three sections stabilized with foam bitumen and 1.0% cement. Water was introduced into these three pavements plus additional accelerated loading, and caused the section with the lowest foam bitumen content to fail. These results showed that foam bitumen and cement had a significant effect on improving the performance of the materials studied. Material samples taken for Indirect Tensile Strength (ITS) and Repeat Load Triaxial (RLT) for laboratory tests showed that the ITS test was a good predictor of the pavement performance giving a clear trend, while RLT results were not conclusive.

## INTRODUCTION

New Zealand is facing a complex problem concerning the supply of high quality aggregates for road construction [1], and a viable alternative to reduce the exploitation of these aggregates is the stabilization or recycling of pavements. Furthermore, New Zealand imports crude oil and therefore its production costs for bitumen are highly dependant on international oil prices. Research has demonstrated that pavement recycling using foam bitumen reduces energy and oil consumption [2, 3], as well as aggregate use, and therefore foam bitumen becomes an attractive alternative for road rehabilitation.

Conversely, pavement designers in New Zealand who are trying to use alternative materials such as foam bitumen in new construction or rehabilitation projects are severely constrained by a lack of data on the performance of a range of stabilized materials. Although foam bitumen has been used for decades, only recently has the study on the performance of foam bitumen mixes gained focus [4]. An important research effort in performance has been undertaken by some researchers at a laboratory level [5, 6] as well as full-scale testing of pavements [7-10], but the investigations cited do not necessarily represent the particular conditions and materials used in New Zealand roads.

At the end of 2006 a full-scale experiment to evaluate the effects of foam bitumen on pavement performance was started at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF), further described in this paper. In the CAPTIF experiment, the effect of foam bitumen and cement stabilization of an unbound granular material was studied. Six pavements were constructed using different contents of bitumen and cement. Accelerated loading was applied to the pavement structures and the pavement responses, such as surface deformation (rutting), surface deflections and strains, were periodically recorded during the execution of the test. The strains were collected at different depths using an array of Emu strain gauges. Deflections were recorded using both a Falling Weight Deflectometer (FWD) and the CAPTIF beam deflectometer, which is a modified Benkelman beam. A total number of approximately 5,710,000 equivalent standard axles (ESAs) were applied to the pavement sections. The results showed that foam bitumen stabilization has an important effect on the performance of the pavements studied, as further detailed in this paper.

## DESIGN, CONSTRUCTION AND LABORATORY TESTING

### Foam bitumen laboratory mix design

A crushed aggregate (H40) was used in this project. The H40 aggregate is a Greywacke (sandstone) rock characterized by its dark color and poorly sorted angular grains. The specific gravity of this aggregate is  $2690 \text{ kg/m}^3$ , the maximum dry density is  $2220 \text{ kg/m}^3$ , and the optimum basecourse moisture content is 4.0%. The quality of this aggregate in terms of performance is considered moderate according to field experience. The aggregate particle size distribution was not directly suitable for foam bitumen stabilization because it was too coarse [11] and therefore it was adjusted using a crusher dust material to bring it into the recommended grading zone. The crusher dust was obtained from a different Greywacke source, and a final mix of 85/15 (aggregate/dust) by mass was found suitable to satisfy the grading requirements for foam bitumen stabilization.

The foam was produced in the Wirtgen WLB 10 laboratory equipment available at the University of Canterbury. The parameter selected to optimize the mechanistic performance of the mixes was the Indirect Tensile Strength (ITS) value. Four mixes were prepared using 1% cement at bitumen contents of 0%, 2%, 3% and 4%, following a mix design method similar to that described in the South African interim guidelines for the design and use of foam bitumen-treated materials [11]. The 150-mm diameter specimens were compacted using a vibratory hammer and left for two weeks to cure at room temperature ( $20^\circ\text{C}$ ). The laboratory ITS trends showed an optimum at approximately 2.8% bitumen content.

### **Structural design of pavements**

The structural design of pavements was carried out using the South African interim guidelines [11] and the New Zealand supplement to the AUSTROADS [12] pavement design guidelines. Both utilize a mechanistic empirical approach for the design of pavements, and the design took into consideration the mechanical properties of the material having the optimum foam-bitumen content determined in the laboratory study (2.8% bitumen, 1.0% cement).

Details of the structural design are not presented in this paper, but a 200-mm basecourse combined with a relatively weak (60-80 MPa) subgrade provided a pavement structural capacity close to 1,000,000 ESAs of 80 kN using both the design methods.

### **CAPTIF description and layout design**

CAPTIF is located in Christchurch, New Zealand. It consists of a 58-m long circular track contained within a 1.5-m deep and 4.0-m wide concrete tank in which the moisture content of the pavement materials can be controlled and the boundary conditions are known (Figure 1a). A center platform carries the machinery and electronics needed to drive the system. Mounted on this platform is a sliding frame that can move horizontally by 1 m. This radial movement enables the wheel paths to be varied laterally and can be used to have the two “vehicles” operating in independent wheel paths. At the ends of this frame, two radial arms connect to the Simulated Loading and Vehicle Emulator (SLAVE) units [13].

CAPTIF enables up to six pavement sections of about 10-m length each to be tested. The objective of this experiment was to study the effect of adding foam bitumen and cement to an untreated granular material. Thus, four sections were stabilized using 1% cement at different bitumen contents. One section was retained as a control with the H40 material only, and another section had foam bitumen only, to separate the effects of the foam bitumen with the cement. A top view of the pavement test track is presented in Figure 1b, in which the six pavement sections are depicted. The sections were named B12C10, B14C10, B28C10, B00C10, B00C00 and B22C00, where the first two digits (after B) indicate the bitumen content, and the last two (after C) indicate the cement content. For instance, section B14C10 was built adding 1.4% of foam bitumen and 1.0% cement.

### **Materials and construction**

#### *Subgrade*

The top 525 mm of the subgrade was clay, extended in lifts of 225, 150 and 150 mm, and compacted using a roller available at CAPTIF. Once preparation of the three layers was completed, FWD tests were conducted to evaluate subgrade homogeneity. Once the construction of the subgrade was finished, FWD deflections of the subgrade surface were measured by applying a pressure of 470 kPa (total load of 33 kN) to verify the layer homogeneity. The peak deflections showed an average of 1.510 mm with a standard deviation of 0.177 mm (Coefficient of variation, CV, 11.7%), which is considered fairly homogeneous for this type of subgrade material. A simple back-calculation analysis yields a subgrade stiffness of 60 MPa approximately, which is in agreement with the target stiffness from the structural design of pavements.

#### *Stabilization process*

Two hundred tonnes of H40 crushed aggregates were transported to Christchurch. The material was delivered in two loads during the days before construction (Figure 2). About 30 tonnes of AP5 crusher dust material was imported from a local quarry.

The CAPTIF building is relatively small for large road construction machinery and therefore it was not feasible to directly stabilize the materials in place. Hence, the aggregate was blended with bitumen and/or cement outside the CAPTIF.

For the stabilization process, 440-mm deep trenches were excavated outside the CAPTIF building. A 340-mm layer of H40 crushed aggregate material was laid in two lifts and compacted to 95% of maximum dry density ( $2110 \text{ kg/m}^3$ ) at its optimum moisture content (4.0%). Later, a 70-mm thick layer of AP5 crusher dust was spread and compacted to 95% maximum dry density ( $1820 \text{ kg/m}^3$ ) at

optimum moisture content (9.0%). The thickness ratio 70/340 yields approximately the target mass ratio of 15/85 obtained in the laboratory mix design. Once the untreated material was ready the trenches were stabilized with the recycling machine. The stabilized material was transported into the CAPTIF building (located about 50 m from the trenches) by loaders. During this process, material samples were taken for laboratory testing described later in this paper. A paver was used to place the basecourse material in two layers of 100 mm each and a steel roller was used for compaction. As the CAPTIF steel roller is lighter than a roller used in normal field construction, the basecourse was compacted in two lifts to account for the lower compaction energy applied. Nevertheless, the same compaction effort was applied to all stabilized pavements. The time between trench stabilization and final compaction of the stabilized basecourse layer for one pavement section was between 2 to 3 hours.

The construction of the control unbound granular section (B00C00) was slightly different. Instead of using a mix of aggregate and crusher dust, only the unmodified H40 aggregate material was used and laid in a single layer of 200 mm. The particle size distribution in this section was not exactly the same as the other sections, but the incorporation of the AP5 crusher dust was part of the stabilization process.

Before laying the final surface layer, the sections were cured at ambient temperature for 30 days.

#### *Surface layers*

The surfacing was constructed 30 days after construction of the basecourse layers. All sections were sealed with a single coat chipseal. After a week to allow the chipseal to set up, all sections were surfaced with a skim coat of AC10 hot mix covering the top of the chipseal. The approximate thickness of this surface was 20 mm. Before the sealing, density and moisture measurements were taken using a nuclear gauge directly over the basecourse. Dry densities and moisture contents are included in Figure 1b.

During the execution of the experiment and after the application of 200,000 load cycles, the original thin surface started to show wearing. A thin hot mix asphalt (HMA) layer of 30 mm was laid over the original surface, leading to a total surface thickness of approximately 50 mm for the rest of the project.

#### **Instrumentation**

The pavement instrumentation at CAPTIF includes 3D Emu [14] soil strain transducers to measure the vertical, transverse and longitudinal strains in the pavement. The soil strain measuring system determines strains with good resolution ( $\pm 50 \mu\text{m/m}$ ). Details of the system can be found in Steven's thesis [15]. The strain coils were installed during the formation of the subgrade and the basecourse layers, to minimize the disturbance to the materials.

The Emu strain coils were located coaxially at a spacing of 75 mm, directly under the inner wheel. The reported depth of the vertical strains corresponds to the midpoint between two coils, while the reported depth of the longitudinal and transverse strains corresponds to the coil depth. The 3D Emu stacks were located at stations 2, 11, 25, 31, 40 and 52 (Figure 1b). A transverse profile of the final pavement structure, the placement of the wheels, and the location of the coils are presented in Figure 3.

Other measurement systems used at CAPTIF during testing are an FWD, the CAPTIF deflectometer (which is a modified Benkelman beam), and a transverse profilometer.

#### **Laboratory testing**

##### *Sampling, specimen preparation and testing*

During the construction of the basecourse layers, samples were taken for ITS and repeated load triaxial (RLT) tests. The ITS samples with dimensions of 150-mm diameter and 100-mm height were prepared using vibratory compaction. The samples were cured for two weeks and tested in a constant displacement loading machine at a rate of 50.8 mm/min and at room temperature (20°C). Only samples with foam bitumen were prepared for ITS testing. The field samples were not soaked after curing.

Large triaxial samples (150-mm diameter and approximately 300-mm high) were also prepared using vibratory compaction. The samples were cured for 28 days in double-sealed plastic bags and were

not soaked after curing. The stress sequence proposed by the New Zealand standard for triaxial testing [16] was followed. The standard applies six stress stages, where the first ("stage 0") is a pre-conditioning stress stage. Each stress stage consists of 50,000 haversine load cycles of 250 mSec. The confining ( $\sigma_c$ ) and deviator ( $\sigma_d$ ) stresses applied were included in the test results (Figure 4b). Only one specimen per foam bitumen content was prepared and tested at room temperature (20°C). The resilient moduli were recorded during these tests at each stage, but only the average modulus is reported in this paper.

### *Results*

The ITS results for the three mixes used in this CAPTIF experiment (Figure 4a) show an increase in strength with more binder content for the materials constructed with foam bitumen and cement. The material from section B28C10 has almost double the strength of sections B12C10 and B14C10, indicating that the basecourse material placed in section B28C10 was considerably stronger than that in the other sections. The ITS values from section B22C00 were considerably lower than samples with cement, indicating that cement increases the strength of the material. The ITS values measured on samples prepared during the laboratory mix design are also included in Figure 4a, indicating that laboratory-mixed materials had similar properties to those obtained in the field.

The RLT permanent deformation versus the number of load cycles from each stress stage is presented in Figure 4b. It is observed that samples from sections B00C00 and B2200 failed in Stages 3 and 6, respectively, while all the samples at 1% cement performed well. Of the specimens with 1% cement the measured total permanent deformation increases with increasing foam bitumen content (Figure 4b) indicating that, under RLT conditions, the introduction of foam bitumen reduces the strength of the material.

The average resilient moduli for materials with no cement were considerably lower than those for cemented materials (Figure 4c). Little difference was measured among the cemented specimens at different bitumen contents, indicating that foam bitumen has little effect on the resilient modulus measured in RLT tests. The final permanent deformation measured in the RLT tests is also included in Figure 4c. The trends observed in the RLT tests seem to contradict the ITS results for the materials obtained from the sections at 1% cement.

## **EXPERIMENTAL PROCEDURE**

### **Loading sequence and speed**

The load was a dual truck tire with a separation of 350 mm between the centers of the tires inflated to 700 kPa. The original project intended that a constant loading of 40 kN would be applied for each SLAVE unit. However, since little rutting was measured during the early stages of the project, the load was increased to 50 kN at 150,000 load cycles. At 502,000 load cycles the load was increased again to 60 kN to induce a failure in the pavement sections.

The speed of the vehicles was kept constant at 40 kph during most of the project. The load was applied on one wheel path with a lateral wandering of 100 mm. During the strain measurements the lateral movements of the wheels were restrained to ensure that the wheels rolled over the strain instrumentation, as shown in Figure 3.

By the end of the test little difference was found in the rutting measurements of sections stabilized with foam bitumen and cement (sections B12C10, B14C10 and B28C10). To accelerate the surface deformation in these sections it was decided to cut part of the pavement sections down from the HMA surface to the top of the basecourse (50 mm-deep cuts). The cuts were 200 mm apart, and the surface was sawed from stations 3 to 6 in section B12C10, from 14 to 17 in section B14C10, and from 20 to 23 in section B28C10. Once the cutting job was finished, water was uniformly applied over the surface. With a constant water flow, an additional 60 kN load cycles were applied.

### **Data collection**

The strain measurements were taken from the beginning to the end of the test at several stages, at SLAVE speeds of 10 and 40 kph. Vertical surface deformations were taken at each station at the same intervals. The rutting that was measured after the construction of the HMA overlay was added to the initial rutting measurements to calculate the total rutting.

The FWD testing was carried out before the trafficking (0 load cycles) and after the application of 1,000,000 load cycles. The initial testing was conducted at a standard 40 kN load at different transverse and longitudinal locations of each pavement section.

CAPTIF modified beam tests were conducted during the initial phase of the project (0 to 35,000 load cycles) and during the last stage (502,000 to 1,326,000 load cycles), applying SLAVE loads of 40 kN and 60 kN respectively. The speed of the wheels during the beam test was about 6 kph.

### **Post-mortem analysis**

Trenches were excavated in each section at the end of the test, and the levels of each pavement layer in each of the sections were recorded to identify the plastic deformation that may have taken place. The locations of some basecourse strain coils were recorded to estimate the potential plastic deformation in the basecourse layers. Material samples were taken for binder extraction [17], moisture content and visual assessment.

## **PAVEMENT TEST RESULTS**

### **Rutting**

The averaged rutting measurements for each pavement section are presented in Figure 5a. In this figure, the number of load cycles has been converted to ESAs of 80 kN in the second x-axis, assuming a fourth power law. The curves presented show the typical behavior of pavements with a bedding-in phase during the initial vehicle loading, followed by a plateau phase. When the load was increased to 50 kN another increase in the rutting rate was observed. From 300,000 load cycles (after constructing the HMA overlay) the rutting increased approximately linearly up to 1,000,000 load cycles for all sections.

After 1,000,000 load cycles, sections B00C10, B00C00 and B22C00 started to show large amounts of heaving and rutting, while sections B12C10, B14C10 and B28C10 performed well, and little difference among them was observed.

### **Deflection tests**

CAPTIF beam and FWD deflections are presented in Figure 5b. The results correspond to deflections measured before the trafficking of the sections (0 load cycles), and for which a load of 40 kN was applied in both deflection tests. The trends observed at this stage were relatively constant throughout CAPTIF test. The beam and FWD provided similar results, illustrated by parallel curves fitted to the results. In general, FWD deflections were lower than beam deflections, and this could be caused by the shorter load pulse applied by the FWD.

The unbound section (B00C00) shows considerably higher deflections in comparison with the other sections. Both cement and bitumen have an important effect in reducing the deflections of the pavements studied, as shown by the lowest deflection recorded in the section at the highest bitumen content and 1% cement (B28C10).

### **Strain measurements**

Only two sets of vertical strain measurements are presented in this paper, and they were taken after the application of 502,000 and 1,326,000 load cycles. The wheel load applied in this part of the test was 60 kN and the vehicle speed for the results presented here is 10 kph (see the loads in Figure 5a). The trends observed at other stages of the test remained similar, indicating that the modulus of the stabilized pavements remained relatively constant during the experiment. This contradicts other full-scale experiments on foam bitumen pavements [7, 11] where an important reduction in the modulus has been reported. However, in those experiments the cement content (2.0%) was higher than the foam bitumen

content (1.8%) and therefore the behavior of the pavements is not representative of the materials studied in the CAPTIF test.

To better examine the effect of foam bitumen the measured strains were plotted against the bitumen contents. In Figure 6 are presented the compressive vertical strains measured in the basecourse (depth=112.5 mm), the tensile longitudinal strains measured close to the bottom of the basecourse layer (depth=150 mm), and the vertical compressive strain close to the top of the subgrade (depth=262.5 mm). The locations of these strains within the pavement structure have been recognized as critical points by the current design methods for foam bitumen pavements [11, 12].

The vertical strains (Figure 6a) measured at sections with 1% cement were considerably lower than those of the other two sections (B00C00 and B22C00). Measurements also indicate that foam bitumen has a small effect in the compressive vertical strains measured in sections at 1% cement. Figure 6b illustrates that cement has a large effect in the reduction of the longitudinal strains. Also, these strains are reduced by 50% when foam bitumen is added. The compressive vertical strains measured at the top of the subgrade (Figure 6c) of the control section (B00C00) were considerably higher than the other sections. In the other sections the general trend was that these strains were lower at higher bitumen contents.

### **Final wet testing**

The introduction of water and accelerated load to the sections stabilized with foam bitumen and cement induced further deformation and surface cracking in the pavement sections. Nevertheless, the water penetrated into the subgrade causing swelling of this layer and modifying the final levels of the pavement structure. After the application of an additional 42,000 load cycles under wet conditions, Section B12C10 started to show extensive cracking and further surface deformation in comparison with the other two sections, with evidence of some loss of fines. Conversely, no cracking was observed in sections B14C10 and B28C10.

### **Post-mortem analysis**

The original vertical distance between the strain coils during the construction of the pavement sections was 75 mm (Figure 3). During the excavation of the pavements the vertical position of the basecourse coils was recorded again to identify any possible permanent deformation within the basecourse layers. The position was measured using a simple ruler and transverse beam lined up across the pavement station marks, with an estimated precision of  $\pm 1$  mm. In stations 2 (B12C10) and 52 (B22C10) it was not possible to recover the coils. The measured separation of the coils in stations 11 (B14C10) and 25 (B28C10) was 75 mm, suggesting that most of the surface deformation in these sections was accumulated in the subgrade layer. Conversely, the sensors recovered from stations 31 (B00C10) and 40 (B00C00) were displaced 4 mm and 5 mm respectively, showing that permanent deformation had occurred in the basecourse.

Samples for moisture content determination from the upper and lower levels of the basecourse, as well as from the subgrade, were obtained during the post-mortem analysis. The results are not presented here, but they indicated that water had penetrated into the sections with foam bitumen and cement as well as the other three sections. Bitumen extraction tests confirmed the binder contents that had been added in each section.

## **INTERPRETATION AND DISCUSSION OF RESULTS**

The pavement test results presented indicate that stabilization using foam bitumen and cement improved the performance of the pavements. The rutting of sections B12C10, B14C10 and B28C10 was consistently lower than in the other three sections.

Materials without cement showed comparatively poor behavior in the laboratory tests which indicates that active fillers are important contributors for developing the early strength of the materials studied. However, sections B00C00 and B22C00 without cement both performed fairly well in the



CAPTIF tests in comparison. This could be explained by the low moisture contents (see Figure 1b) obtained in these sections after construction, and which were confirmed in the post-mortem analysis.

The laboratory tests showed contradicting trends for materials with 1% cement. The ITS results for 1% cement indicate that at higher foam bitumen contents the strength of the materials increases (Figure 4a). This is the normal behavior of foam bitumen mixes for which strength increases to an optimum bitumen content, after which the ITS value drops [18, 19]. Similar trends are observed from indirect tensile resilient modulus tests [20, 21]. Conversely, permanent deformation RLT specimens at 1% cement show an opposite trend to those of the ITS results, in that the higher the bitumen content, the higher the final permanent deformation (Figure 4b). In addition, the average Resilient Modulus measured during the RLT tests (Figure 4c) shows a peak in the specimen with 1.4% bitumen and 1% cement, and decreases in the specimen with 2.8% bitumen and 1% cement. This peak value is slightly higher than the other values measured on specimens at 1% cement, indicating that foam bitumen does not have an important effect on the resilient modulus measured under RLT stress conditions.

The drawback of the RLT testing results obtained for this experiment is that only one specimen was tested after 28 days of curing. However, comparable RLT trends (permanent deformation and resilient modulus) were also observed in several RLT specimens tested during the preliminary laboratory study at CAPTIF, which are not presented in this paper. In addition, similar results have been reported by other authors [7,22] who, along with others [23, 24], observed that Unconfined Compressive Strength (UCS) test results showed the foam bitumen to have a minor effect on the compressive strength of materials with cement.

The laboratory results are related to the strain measurements taken in the basecourse. The vertical strain measured in the basecourse (Figure 6a) has a similar trend to those of the resilient modulus in Figure 4c. The longitudinal strain measured close to the bottom of the basecourse (Figure 6b) follows the trend of the ITS tests (Figure 4a).

Because the basecourse was placed over a fairly weak subgrade, the tensile behavior (related to indirect tensile tests) had a dominating effect on the actual pavement behavior. A simple multi-layered linear elastic model of the pavements studied showed that only the upper 25% of the basecourse is loaded under a stress condition comparable to the RLT permanent deformation stress conditions (vertical and horizontal compressive stresses). The middle of the basecourse (where the basecourse strain coils were located, Figure 3) was affected by a combination of low compressive and tensile horizontal stresses, while the bottom of the basecourse layer is under compressive vertical stresses and horizontal tensile stresses.

The vertical strains measured at the top of the subgrade (Figure 6c) follow a similar trend to those of the deflections (Figure 5b) indicating the large effect of the subgrade on the elastic response of the pavements. The lowest deflection was measured in section B28C10, caused by the reduction of the horizontal strains at higher bitumen content.

The wet testing at the end of the CAPTIF experiment indicated that 1.4% and 2.8% foam bitumen contents considerably reduced the moisture susceptibility of the stabilized materials. However, only a reduced number of additional load cycles were applied under these conditions and little difference was observed between sections B14C10 and B28C10 in terms of rutting or surface cracking.

The curing period of the pavements studied was fairly short in that the trafficking of the sections was completed only about ten months after construction. The results obtained in this short period indicate that foam bitumen affects development of the early strength of the pavement materials.

## CONCLUSIONS AND RECOMMENDATIONS

A full-scale experiment on foam bitumen pavements with different binding contents is presented along with the following conclusions and recommendations drawn from the results presented in this paper:

- The rutting measured in sections B12C10, B14C10 and B28C10, after the application of 1,326,000 load cycles (5,710,000 ESAs) was the lowest, showing that the addition of foam bitumen significantly improved the performance of the materials with 1% cement that were studied in this research. The sections B00C10 and B22C00 and the control untreated section (B00C00) showed large

amounts of rutting and heaving by the end of the test. Little difference was observed within the sections stabilized with foam bitumen and 1% cement.

Based on these results, it is recommended that adding 1% cement has to be considered in the construction of foam bitumen mixes.

- Pavement section B28C10 was designed to carry 1,000,000 ESAs of 80 kN with two design methods. However, after the application of 5,710,000 ESAs little rutting was observed, indicating that current design methods for foam bitumen pavements are over-conservative.
- To differentiate the rutting performance of the sections stabilized with foam bitumen and cement, water was introduced through surface cuts. After the application of additional accelerated traffic load, section B12C10 started to show surface cracking, while sections B14C10 and B28C10 performed well, indicating that foam bitumen contents close to the optimum ITS reduce the moisture susceptibility of pavements.

Based on these results, it is recommended to adopt foam bitumen contents that maximize ITS in pavements that have a potential risk of water being introduced into the pavement layers.

- The deflections of section B28C10 were lower than those of the other sections, while the untreated section (B00C00) showed the largest values.
- The ITS values of section B28C10 were double those of sections B12C10 and B14C10, and the ITS values from section B22C00 were the lowest. The results indicate that ITS was a reasonably good predictor of the general performance of the pavements studied.

Therefore ITS is recommended as a test to measure the strength properties of foam bitumen mixes.

- The triaxial (RLT) testing showed that the addition of 1% cement significantly enhanced the quality of the foam bitumen mixes. However, the results obtained from the specimens at 1% cement at different bitumen contents showed that an increase in foam bitumen content increases the permanent deformation in the laboratory tests. The resilient modulus values measured during the triaxial testing could not detect the important improvement in stiffness of section B28C10.

This shows that RLT testing does not necessarily detect the effect of foam bitumen in materials with cement, and it is recommended that complementary tests such as ITS tests should be conducted to assess the properties of foam bitumen mixes.

- The basecourse strain measurements follow relatively well the trends observed in most of the laboratory results. The ITS results show a relationship with the longitudinal strains, while the compressive vertical strains are related to the triaxial resilient modulus. Little difference was observed in compressive vertical strains measurements in sections with 1% cement and different foam bitumen contents, indicating that foam bitumen has little effect when the basecourse is loaded in compression. The vertical compressive strains measured at the top of the subgrade followed the surface deflection tests, indicating that surface deflection was controlled by the subgrade elastic response.

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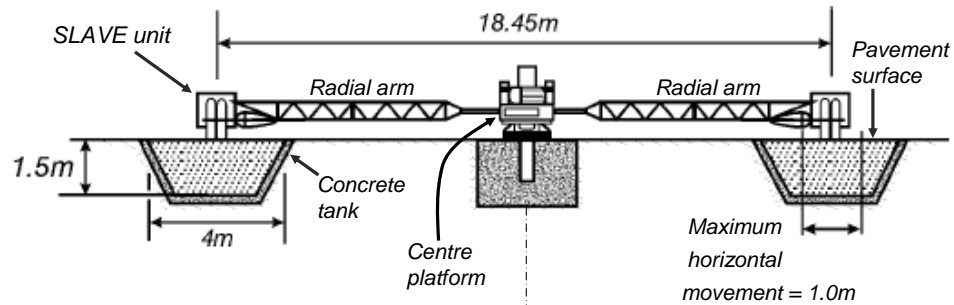
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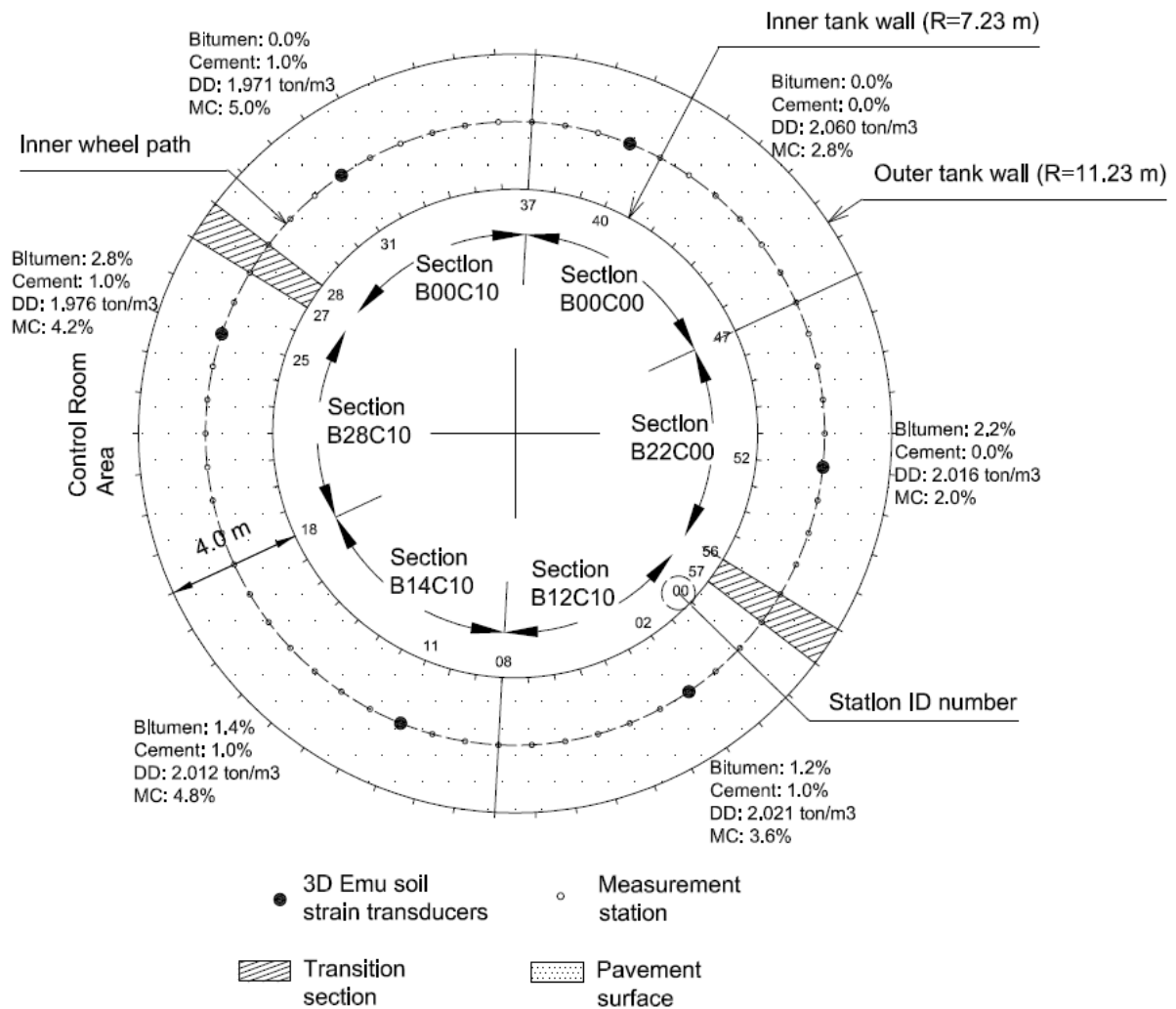
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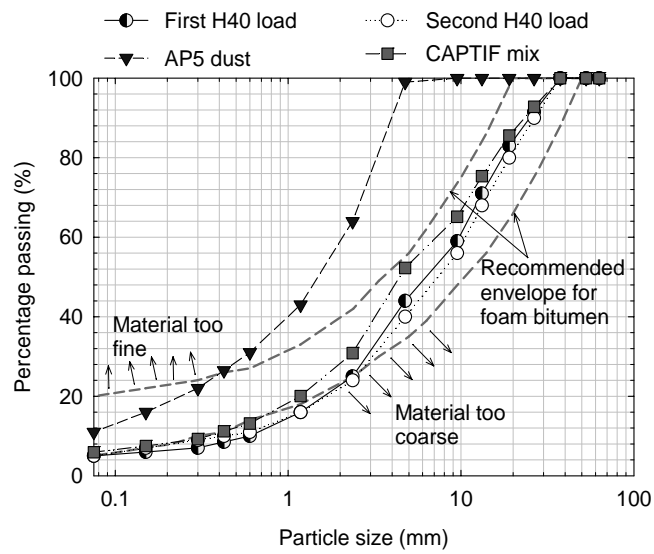
(a)



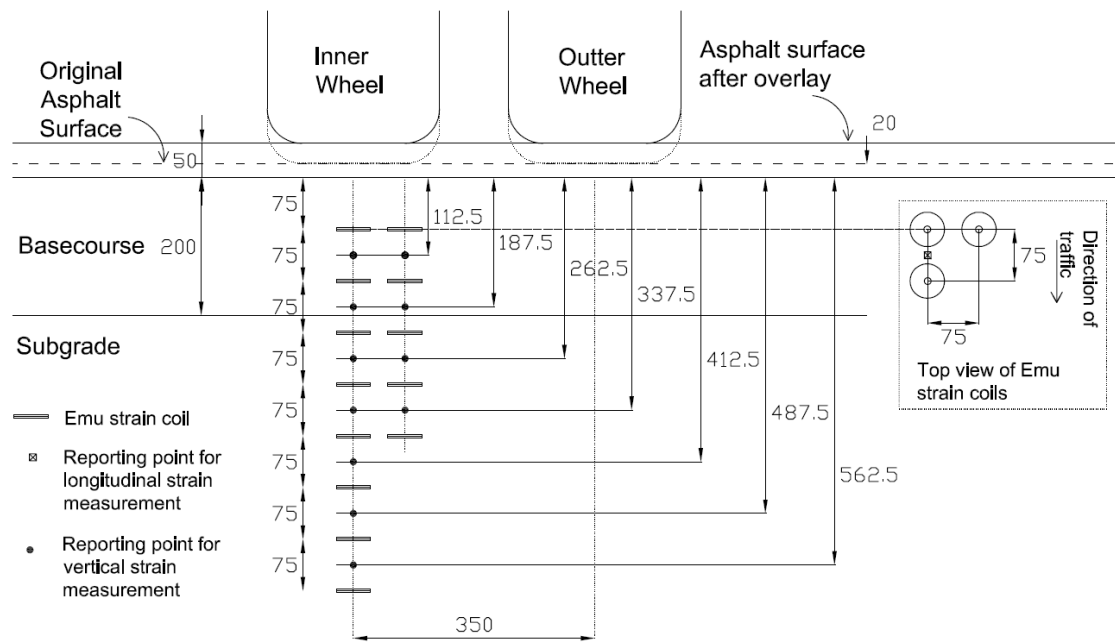
(b)



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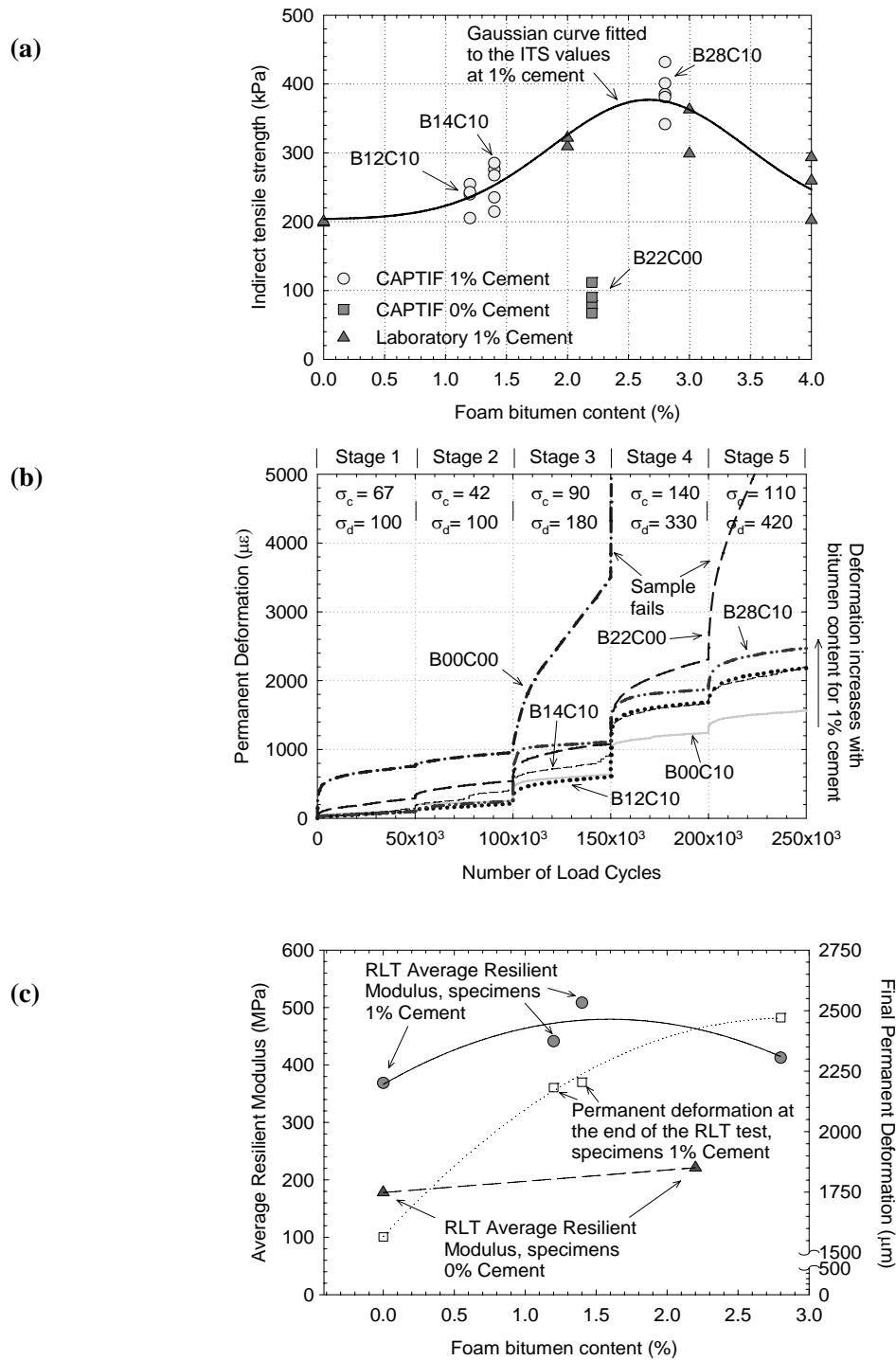


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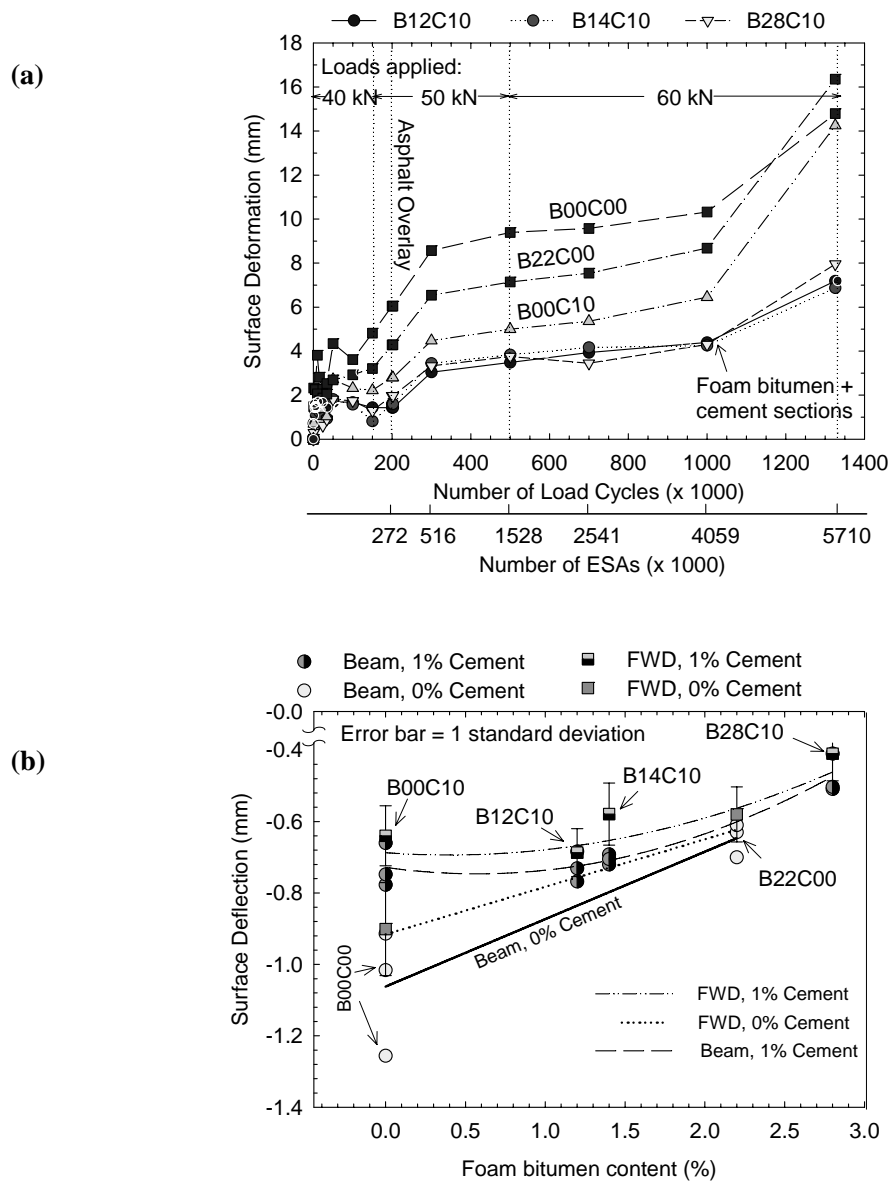


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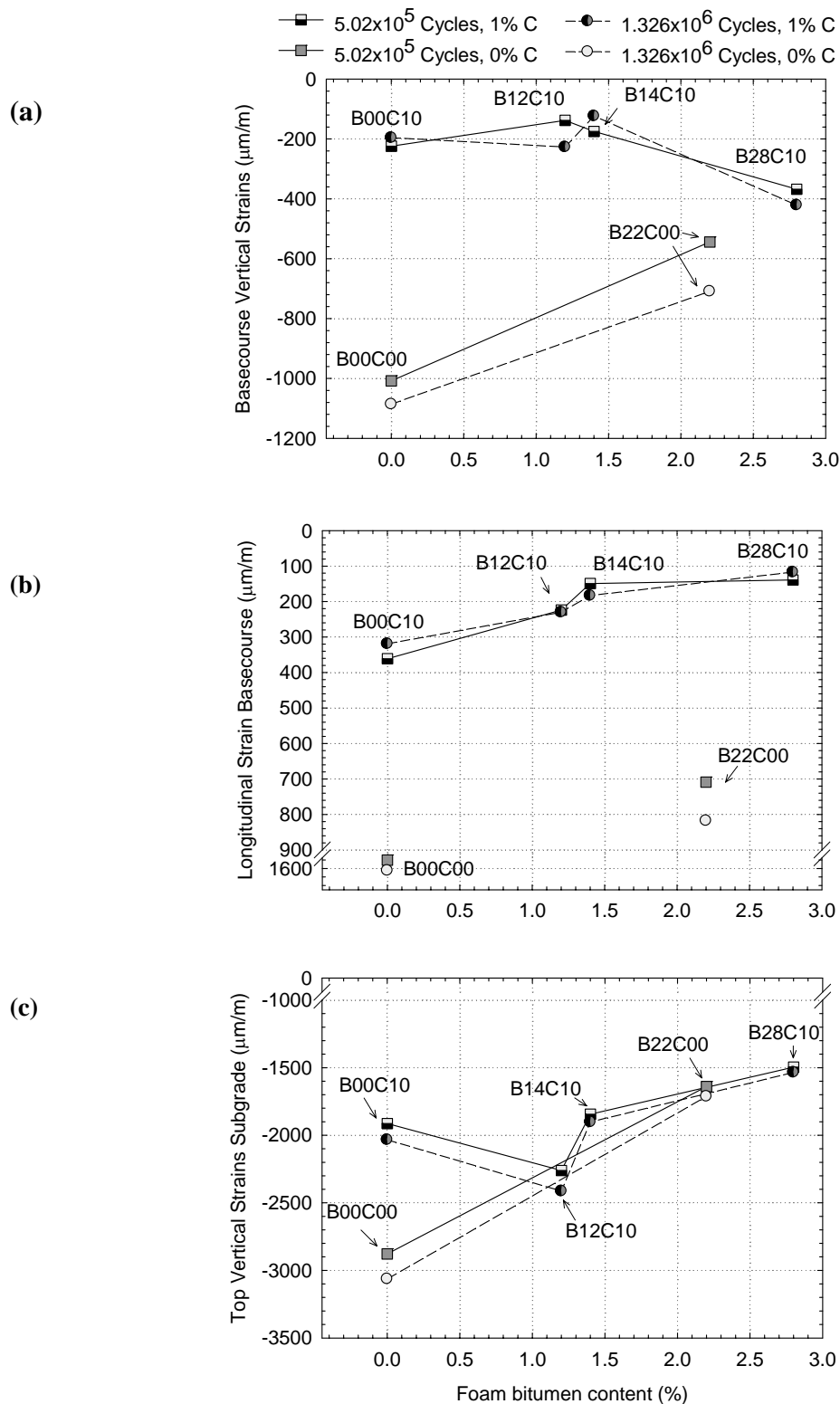




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